International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 7, Issue 6, Dec 2017, 351-358

EXPERIMENTAL INVESTIGATION OF HIGH SPEED DRILLING OF GLASS FIBER REINFORCED PLASTIC (GFRP) COMPOSITE LAMINATES MADE UP OF DIFFERENT POLYMER MATRICES

R. RAJA & SABITHA JANNET

Assistant professor, Mechanical Department, Karunya University, Karunya Nagar, Coimbatore, Tamil Nadu, India

ABSTRACT

Near net shape manufacturing is adopted in the synthesis of polymer matrix composite laminates. Joining of this laminates is critical to its intended application as engineering structural material. Mostly rivets are used for joints, success of these joints dependent on the geometrical and dimensional integrity of the holes drilled in these laminates. This work studies and compares drilling performance on laminates made up of different matrices such as Epoxy, Bisphenol and vinyl ester. Thrust force (N), during the drilling process and assessment of delamination factor after the process, could reveal the dimensional integrity of the holes to a larger extent. This paper discusses the effect of matrices of laminates, on the machining process and also, justifies the widespread use of epoxy as matrix material for Glass Fiber Reinforced Plastic (GFRP) composite laminates.

KEYWORDS: GFRP, De lamination Factor, Thrust Force, Spindle Speed & Torque

Received: Oct 16, 2017; **Accepted**: Nov 06, 2017; **Published**: Nov 16, 2017; **Paper Id.**: IJMPERDDEC201739

INTRODUCTION

Due to the inhomogeneous and anisotropic nature of the GFRP composite materials, machining of polymer matrix laminates is not as easy as machining of metals. More than one million holes are required in a small engine air craft mostly for fasteners. Drilling studies on Glass Epoxy GFRP composites are done extensively in the forms of concentration on tool materials and geometry, roughness of drill surface, thrust force and delamination at entry and exit, with respect to the influence of point angle of tool, variable feed rate, and variable spindle speed. GFRP) [5]. A study on CFRP/Ti stacks using variable feed rate (high feed rate for CFRP and low feed rate for Ti) is also carried out. Statistical significance of fibre orientation is also analysed. Damage progression was found to be strongly influenced, by the fiber orientation physical and mechanical properties of the FRP composite [6]. How machining process alters the mechanical properties of laminate preparation is also studied. It has been observed that irrespective the production methods, machining changes the physical and mechanical properties of the laminate[7] For short carbon fiber composites, experimental data shows that the tool wear, the surface finish and the cutting force fluctuate with respect to the depth of cut, the feed rate and the cutting speed[8]. The whole quality parameters analyzed include hole diameter, circularity, peel-up delamination and push-out delamination and Analysis of variance (ANOVA) was determined, for hole quality parameters. The optimum cutting conditions for defect free drilling were found out, by Genetic Algorithm (GA) [9] [10]. The variations of cutting forces with or without onset of delamination, during the drilling operations were analyzed. No major attempt has been made so for, to know the machine ability details on glass, with thermo set resins other than epoxy resin. [11]

EXPERIMENTAL SET-UP

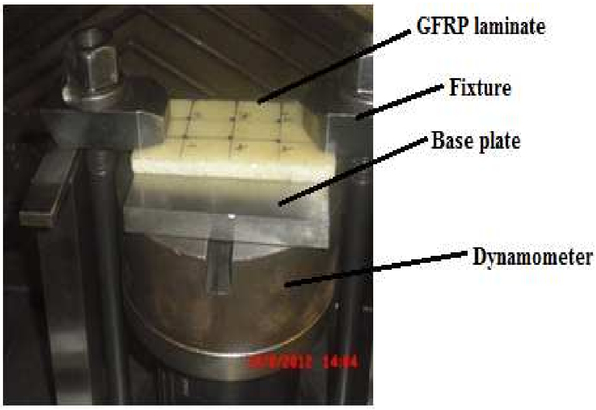


Figure 1: Work Piece Placed Over the Dynamometer

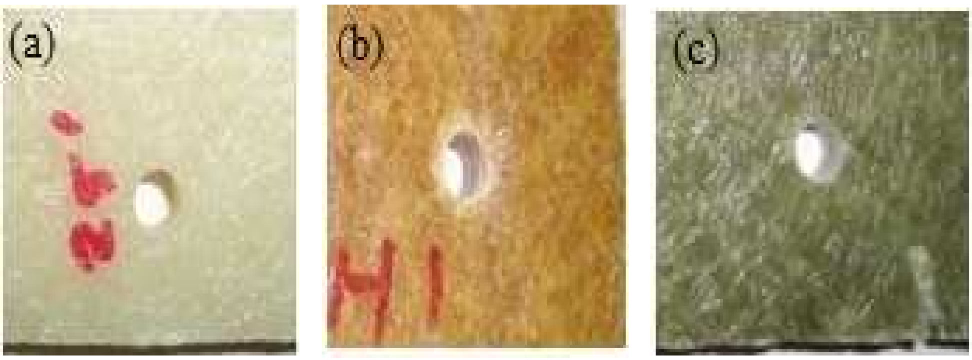


Figure 2: Holes in GFRP Composites with (a) Epoxy (b) Bisphenol (c) Vinyl Ester

Makino vertical machining center-Model S33 is used for drilling holes. This machine has the spindle speed range of 200-20000 rpm and with the accuracy of 0.003 micron and repeatability of 0.002 micron. A Metzer profile projector, with magnification ranges of 10x, 20x and 50x is used to measure the whole diameter. It has linear least count of 10 micron and angular least count of 1 minute.

Preparation of Gfrecs

Glass Fiber Reinforced Epoxy Composites (GFRECs) consists of glass fiber in an epoxy matrix; it was manufactured by hand layup method. The reinforcing material that is the E glass fiber was laid at 45 degree orientation. Hence alternate layers were perpendicular to each other. This arrangement enhances the strength of the composite in all directions. Eight alternate layers of glass fibers of arranged in this manner along with epoxy matrix in between each layer to get the thickness of 5mm. fiber is maintained at 60% by weight in this method. Similarly glass fibers laminates with bisphenol and vinyl ester matrix also prepared. They are cured at atmospheric temperature and pressure. Care is taken to ensure the absence of air bubbles in the laminate. Rollers are rolled over the laminate after each alternate layer

RESULTS AND DISCUSSIONS

Effect of Spindle Speed on Thrust Force

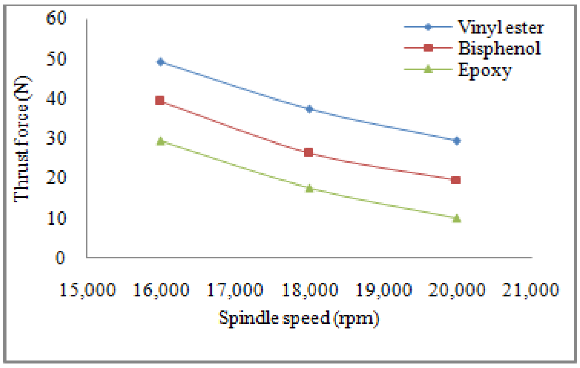


Figure 3: Effect of Spindle Speed (rpm) on Thrust Force

In high speed drilling experiments the torque values were found to be less than 0.1 Nm and negligible when compared to values at low speed drilling hence the thrust force is alone considered for analysis. The thrust force obtained for various spindle speed during the high speed drilling of GFRP is presented in Figure. 3 It can be observed that the thrust force increases with the decrease in spindle speed owing to increase in the temperature of the matrix. Softening of matrix takes place due to the elevated temperature; hence at higher temperature drill bit penetrates the matrix with reduced resistance. This attribute of high speed machining results in lower thrust force

Effect of Spindle Speed on Delamination Factor

Figure 4 and Figure 5 show the effect of spindle speed on delamination factor, at the entry of the hole (peel up delamination) and at the exit of the hole (push out delamination). Push out delamination is higher than peel up delamination for the same set of operating conditions. It is due to the fact that when drill bit approaches the exit it encounters relatively very thin laminate which gives very little resistance for the drill bit. Among the three matrices, lesser delamination occurs for epoxy matrix material. Toughness of matrix plays a critical role in cracking and failure of the laminate. Resin failure occurs even before the total failure of the laminate. Hence being a strong matrix with a higher ultimate tensile strength of 63.80 MPa [13] epoxy matrix gives better results. It justifies the wide spread usage of epoxy as a matrix material for polymer composites.

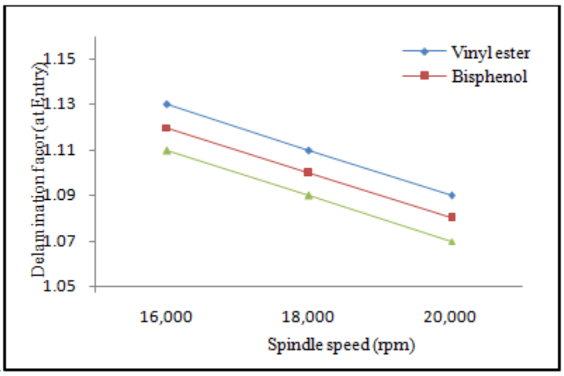


Figure 4: Effect of Spindle Speed on Delamination Factor (at Entry)

Spindle speed has inverse relationship with delamination factor. It enables fine cutting of hole and thereby, gives

hole with less delamination. When drill bit approaches the exit of the hole, it has relatively thin laminate layer to be drilled. Hence, high speed drilling is adopted in drilling of glass fiber reinforced plastics, carbon fiber reinforced plastics and other polymer composite laminates.

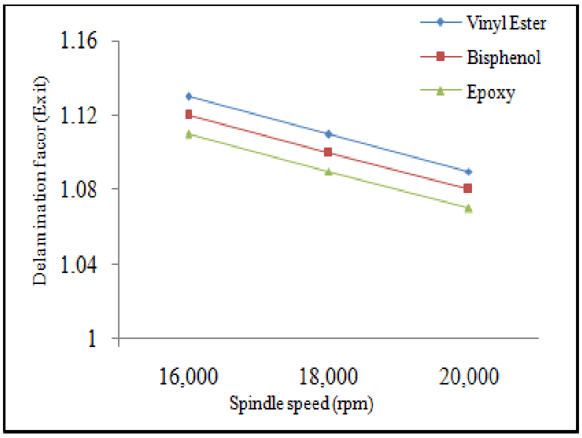


Figure 5: Effect of Spindle Speed on Delamination Factor (Exit)

This thin layer gives less resistance to the drill. Hence, push out delamination is more severe than peel up delamination. On the whole, when spindle speed increases delamination factor decreases. Delamination factor (at exit) or push out delamination is more than the delamination factor (at entry), or peel up delamination.

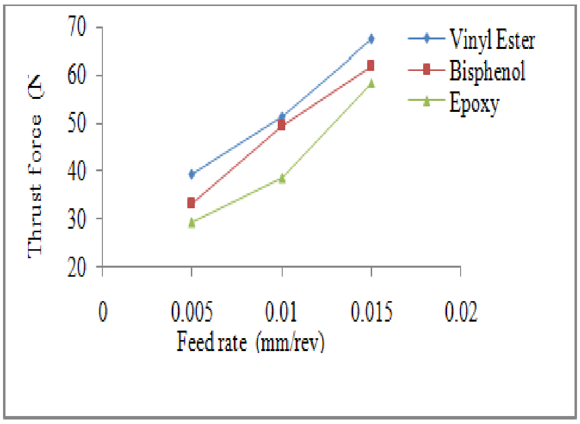


Figure 6: Effect of Feed on Thrust Force

When feed rate increases, thrust force also increases almost in linear manner. This behavior is found in all three matrices. The mechanism of machining depends on flexibility, orientation and toughness of fibers. Typically, lower values of thrust force and delamination factor are desirable, for getting good quality holes. Feed rate has a direct relationship with thrust force. Interaction of spindle speed and feed rate is good on the output responses thrust force and delamination factor

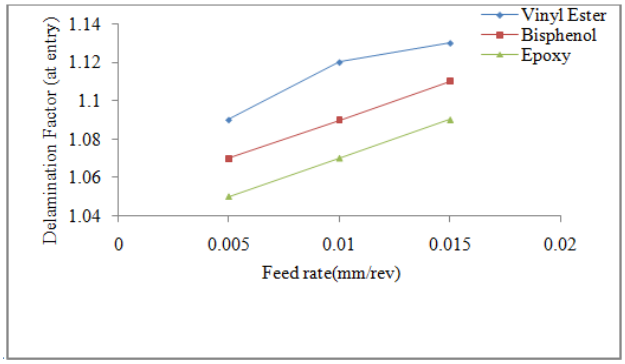


Figure 7: Effect of Feed on Delamination Factor (at Entry)

Feed rate has a greater influence on thrust force, push-out delamination and diameter of the hole. While, lower feed rates reduce thrust fore and push-out delamination, higher feed rates result in holes closer to the nominal diameter. Feed rate has clear and almost linear relationship, with both thrust force and delamination factor

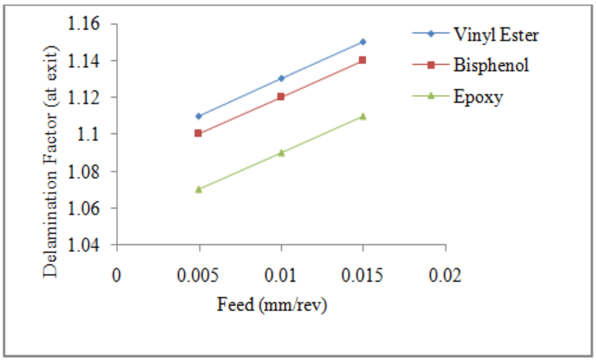
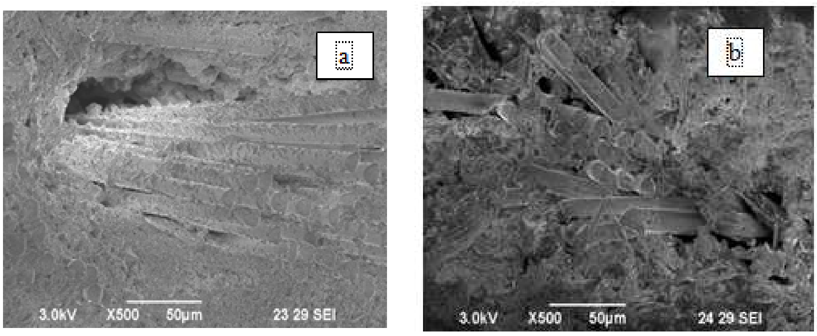


Figure 8: Effect of Feed on Delamination Factor (at Exit)

Fibers were cut in a more uniform manner. It is because of the fact that when fibers were cut in a rapid manner pull out of uncut fibers entangled with cut fibers is minimized



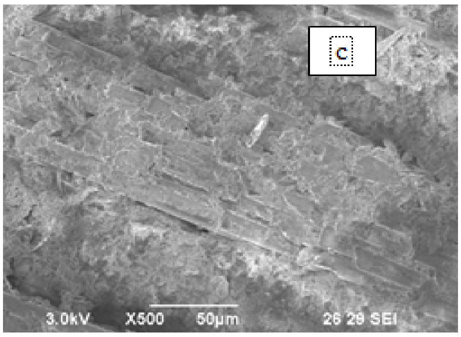


Figure 9: a) SEM Image of GFRP- a) Epoxy Matrix b) SEM Image of GFRP-Bisphenol Matrix c) SEM Image of GFRP-Vinyl Ester Matrix

Figure.9 a) shows scanning electron images of the drilled whole wall surface of GFRP with epoxy resin, bisphenol resin and vinyl ester resins, respectively. In Figure 9.b), the arrangement of fibers and distribution of matrix is shown, in this distribution of matrix is uniform in certain places and they are not uniform in certain places, it is due to uneven distribution fibers, during manufacturing and fiber pull-out during machining operation. Figure 9 c), shows the pattern of fiber breakage in the work piece, which is manufactured with glass and bisphenol resin.

Regression analysis is a statistical tool, to find the influence of process parameter variables on the responses.

$$Thrust\ force = 251.831 - 0.82 * (Spindle\ Speed) + 1.1136 * (Feed\ rate) - 0.7754 * \ (Matrix) \tag{1}$$

$$Delamination\ factor(entry) = 1.0999 - (0.7) * (Spindle\ Speed) + 1.62 * (Feed\ rate) - 0.07\ * (Matrix) \tag{2}$$

$$Delamination\ factor(exit)\ =\ 1077 - (0.93) * (Spindle\ Speed) + 1.72 * (Feed\ rate) - 0.07 * (Matrix) \tag{3}$$

Equations 1, 2 and 3 were developed to have the correlation between the input variables on the thrust force, delamination factor (entry) and delamination factor (exit) is also observed that, for same set of input parameters delamination factor (exit) is higher than delaminating factor (entry). It is very much evident that feed rate has more influence on the output responses followed by spindle speed and matrix material

Table 1.1: ANOVA Analysis on the Response Thrust Force (N)

Factors	DOF	Sum of Squares(S)	Variance (V)	F-Ratio(F)	Pure Sum(S^1)	P-Percent Contribution
Spindle speed(rpm)	2	580.913	290.45	490.916	579.728	8.024
Feed rate(mm/rev)	2	6606.480	3303.15	5574.79	6605.301	91.42
Matrices	2	25.612	12.80	21.62	24.427	0.338
Other Error	20	11.850	0.592			0.214
Total	**26**					**100**

Table 1.2: ANOVA-Analysis on the Response Delamination Factor (Entry)

Factors	DOF	Sum of Squares	Variance	F-Ratio	Pure Sum	P-Percent Contribution
Spindle Speed(rpm)	2	0.008	0.004	64.281	0.007	23.682
Feed rate(mm/rev)	2	0.022	0.11	176.81	0.021	65.816
Matrices	2	0.002	0.001	16.061	0.001	5.636
Other Error	20					4.866
Total	**26**					**100**

Table 1.3: ANOVA-Analysis on the Response Delamination Factor (Exit)

Factors	DOF	Sum of Squares	Variance	F-Ratio	Pure Sum	P-Percent Contribution
Spindle Speed(rpm)	2	0.007	0.003	71.786	0.007	23.2
Feed rate(mm/rev)	2	0.02	0.01	203.325	0.02	66.69
matrices	2	0.001	0	17.892	0.001	5.54
Other Error	20	0	0			4.26
Total	**26**					**100**

Based on the above ANOVA analysis, it is every much evident that feed rate has highest statistical significance on the responses, followed by spindle speed (rpm). Matrix material has very low significance on thrust force and delamination factor.

CONCLUSIONS

- When spindle speed increased there is a considerable decrease in thrust force. The highest spindle speed 20,000 rpm has given less thrust force and delamination.
- When feed rate (mm/rev) is increased thrust force and delamination are also increased. The highest feed rate of 0.015 mm/rev results in higher thrust force and delamination
- Lesser delamination occurs for epoxy matrix material. This phenomenon occurs due to the relatively strong and hard epoxy polymer compared to the other two which are bisphenol and vinyl ester. Delamination factor (F_d) is higher at the exit than at the entrance for all the experimental conditions
- Based on the mathematical models, it is arrived that feed rate has more influence, spindle speed has relatively moderate influence and matrix has less influence on thrust force and delamination factor

REFERENCES

1. *D. Kumar, K. K. Singh, R. Zitoune, Experimental investigation of delamination and surface roughness in the drilling of GFRP composite material with different drills, Adv. Manuf. Polym. Compos. Sci. 2 (2016) 47–56. doi:10.1080/20550340.2016.1187434.*
2. *T. CC, The path towards delamination-free drilling of composite materials, J. Mater. Process. Technol. 167 (2005) 251.*
3. *S. V, Experimental and numerical investigations in conventional and ultrasonically assisted drilling of CFRP laminate, 5th CIRP Conf. High Perform. Cut. 1 (2012) 455.*
4. *P. T, Influence of point angle on drill hole quality and machining forces when drilling CFRP, 5th CIRP Conf. High Perform. Cut. 1 (2012) 471.*
5. *D. JP, Effects of high speed in the drilling of glass fibre reinforced plastic: evaluation of the delamination factor, Int. J. Mach. Tools Manuf. 48 (2008) 715.*
6. *M. ME, Wear resistance and induced cutting damage of aeronautical FRP components obtained by machining, Wear. 271 (2011) 2542.*
7. *Z. L, Effects of hole machining defects on strength and fatigue life of composite laminates, Compos. Part A. 28A (1997) 141.*
8. *M. GWA, Machining optimisation in carbon fibre reinforced composite materials, J. Mater. Process. Technol. 92–93 (1999) 135.*

9. *Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates, Compos. Part B Eng. 43 (2012) 1791–1799. doi:10.1016/J. COMPOSITESB.2012.01.007.*

10. *E. Kilickap, Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite, Expert Syst. Appl. 37 (2010) 6116–6122. doi:https://doi. org/10.1016/j. eswa.2010.02.023.*

11. *L. Durão, J. Tavares, V. de Albuquerque, J. Marques, O. Andrade, Drilling Damage in Composite Material, Materials (Basel). 7 (2014) 3802–3819. doi:10.3390/ma7053802.*

12. *W.-C. Chen, Some experimental investigations in the drilling of carbon fiber-reinforced plastic (CFRP) composite laminates, Int. J. Mach. Tools Manuf. 37 (1997) 1097–1108. doi:https://doi. org/10.1016/S0890-6955(96)00095-8.*

13. *A. Velayudham, R. Krishnamurthy, T. Soundarapandian, Evaluation of drilling characteristics of high volume fraction fibre glass reinforced polymeric composite, Int. J. Mach. Tools Manuf. 45 (2005) 399–406. doi:https://doi. org/10.1016/j. ijmachtools.2004.09.012.*